How Interoperability Saves Money

By Robert E. Chapman, Ph.D.

The pressures of competing in the global marketplace are forcing building control companies, equipment and systems manufacturers, energy providers, utilities, and design engineers to improve performance and reduce costs. One means of meeting this twin challenge is through the development and use of cybernetic building systems (CBS's) that integrate multiple building systems. A CBS is defined as a multi-system configuration that communicates information and control functions simultaneously and seamlessly at multiple levels. The configuration must also allow for two-way communication between the building(s) in which it is installed, utilities, and energy and service providers. The multiple levels of communication and control are based on the BACnet® (*B*uilding *A*utomation and *C*ontrol *net*works) layered protocol architecture.[1,2]

Building systems that can be incorporated into CBS products and services include energy management (e.g., HVAC and lighting), life safety (e.g., fire detection and fire fighting), security (e.g., access control), fault detection and diagnostics, optimal control, and the real-time purchase of electricity. How these systems communicate, interact, share information, make decisions, and perform in a synergistic and reliable manner needs to be addressed on an industry-wide basis if CBSs are to be successful, and if the U.S. is to obtain a significant share of the potential global market for such systems.

To address these needs, NIST's Building and Fire Research Laboratory (BFRL) has launched a multidisciplinary research program to collaborate with industry on the development of CBS products and services and to provide a forum for interoperability testing.

Although CBS products and services have great potential, investments in them will be forthcoming only if industry perceives that the economic benefits outweigh the costs of using such products and services. Being able to demonstrate net economic savings from using CBS products and services will encourage their acceptance and use. This article documents how the use of CBS products and services in office buildings will generate significant net economic savings to the owners, managers, and occupants of those buildings.[3,*]

A CBS Case Study

The case study is divided into two sections. The first section focuses on data and assumptions. The analysis of cost savings from using CBS products and services in office buildings is the focus of the second section.

Data and Assumptions

The data and assumptions underpinning the economic impact assessment deal with five key topics: 1) the base year; 2) the starting and ending points in the study period; 3) the discount rate; 4) the process by which CBS products and services diffuse into the marketplace; and 5) the specification of the base case and the CBS alternative.

The base year for computing all CBS-related costs and savings is 1997. There are two reasons why 1997 was selected as the base year. First, 1997 is the year in which BFRL formed an integrated CBS project team. Second, authoritative and comprehensive construction industry cost data are available for 1997. Thus, cost conversions for previous and subsequent years may be accomplished through the use of a well-defined cost index to equate them to constant 1997 dollars.

The study period begins in 1991 and ends in 2015. Costs and/or savings that occur after 2015 are not included. The study period begins in 1991 because BFRL's research on BACnet had reached a high-level of maturity by that year. BFRL's research on BACnet is crucial to the overall CBS effort, as BACnet provides the communication protocol for all major CBS products and services. The 1991 start date was used in estimating the return on BFRL's CBS-related investments. These investments span the period between 1991 and 2004. The end of the study period is 2015. By 2015, the use of CBS products and services is expected to be widespread.

The CBS economic impact assessment uses a real discount rate of 7% to convert dollar amounts to present values. The

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discount rate is expressed in real terms, since constant dollar estimates of benefits and costs are used. The discount rate is used to convert benefits and costs occurring at different times to the base year. Discounting future amounts to present values is necessary because, even in the absence of inflation, $100 today is worth more than $100 in five years. The procedure used to calculate the present value of net cost savings expected from the use of CBS products and services in office buildings uses standardized practices.[4]

The diffusion of CBS products and services into the commercial marketplace uses two diffusion models. The primary diffusion model, $P_\eta(t)$, gives the proportion of potential users who have adopted CBS products and services by time period t (i.e., the cumulative total), where $t = 1$ corresponds to 2003, the time of first commercial use. The secondary diffusion model, $N_\eta(t)$, gives the proportion of potential users who first install CBS products and services in year t (i.e., new users). In both diffusion models, the subscript η designates the market saturation level (i.e., potential users). For more about the diffusion models used in the CBS economic impact assessment, see Chapman 1999.

To estimate costs and savings due to the use of CBS products and services, it is necessary to specify both a base case and a CBS alternative. The term base case is used to represent the configuration that maintains the *status quo* (i.e., the use of traditional heating, cooling, lighting, and life safety technologies). The CBS alternative is that collection of products and services (i.e., configuration) that provides equivalent or enhanced performance for all features of the base case while satisfying the definition of a CBS given earlier.

Two key differences exist between the two configurations. First, the degree to which the building service features are integrated, automated, and controlled is significantly higher in the CBS alternative. The second difference is that the CBS alternative has the potential to achieve enhanced performance for selected building service features. These differences are crucial in structuring differences in costs (e.g., due to the installation of additional equipment and software to generate improved systems integration, automation, and control) and savings (e.g., energy cost savings due to improved performance of HVAC and lighting systems) between the two configurations. Quantitative measures of these differences are now summarized.

Type of Cost Savings	Value of Cost Savings in 1997 Dollars $/m² ($/ft²)
Energy	$1.71 ($0.16)
Maintenance	$1.60 ($0.15)
Repair and Replacement	$0.66 ($0.06)
Occupant Productivity	$4.20 ($0.39)

Table 1: Annual per unit cost savings due to the use of CBS products and services (2003–2015).

The enhanced performance of HVAC and lighting systems under the CBS alternative *vis-à-vis* the base case produces four types of benefits or cost savings. These benefits and cost savings are: 1) lower energy costs; 2) lower maintenance costs; 3) lower repair and replacement costs; and 4) increased occupant productivity. The first three types listed are readily classified as cost savings. While increased occupant productivity may be thought of as a benefit, we classify it as a type of cost savings since it reduces the occupant company's cost of business for a given level of output. Estimated values for each type of cost savings are given in *Table 1*.

These estimates were generated via a three-step process. First, source documents were identified from which to develop estimated values for the annual per unit costs of energy,[5,6] maintenance,[7] repairs and replacements,[7] as well as the annual salary costs per unit of floor area.[8,5] Second, ranges of estimated annual percent savings per unit of floor area were derived through reference to the literature[9,10] supplemented by a series of interviews with industry experts (e.g., design engineers and facility owners and operators). Third, feedback from industry experts was used to develop consensus values for each type of cost savings.

The consensus values given in *Table 1* are considered conservative (i.e., they have a high probability of being achieved). Readers interested in a more detailed description of this process or the implications of varying per unit cost savings about the consensus values are referred to the NIST CBS impacts report.[3]

If building owners and managers install the CBS alternative rather than the base case, they can expect to bear four types of additional costs. These costs are: 1) higher first costs; 2) higher evaluation costs; 3) increased costs of adapting new building products and services to industry use; and 4) increased training costs.

With the exception of higher first costs, the three remaining costs may be classified as new-technology introduction costs. Ehlen and Marshall[11] define new-technology introduction costs as those costs covering the activities that bring the material/product from the research laboratory to full field implementation. New-technology introduction costs include the extra time and labor to design, test, monitor, and use the new technology. However, Ehlen and Marshall demonstrate that new-technology introduction costs disappear once the technology enters full implementation and its application has become routine.

Higher first costs from installing a CBS are expected due to the increased use of sensors. The use of open systems is not expected to increase first costs. Experiences with BACnet[9] and discussions with industry experts lead to the conclusion that any "premium" attached to the costs of open systems would be quickly eliminated through a competitive procurement process. In addition, the increased first cost associated with the increased use of sensors is likely to decline over time due both to improved sensor technology and increased competition. However, in keeping with the conservative approach employed in this economic impact assessment, the sum of these four types of additional costs are held constant throughout the study period. Specifically, an additional cost of $10.76 per square meter ($1.00 per square foot) is assigned when an office building first installs the CBS

alternative. Discussions with industry experts were used to specify a conservative value for this additional cost.

Analysis Results

Three types of information were combined to generate an estimate of cost savings nationwide. These three types of information are: 1) the diffusion models; 2) the per unit cost savings for energy, maintenance, repairs and replacements, and occupant productivity; and 3) the additional costs to building owners and managers for installing CBS products and services. Estimates were produced for each year from 2003, the time of first use, until 2015. Each year's net cost savings was then discounted to a present value and summed to get the present value of cost savings nationwide. The present value of cost savings nationwide is a key indicator of the merits of installing CBS products and services in office buildings.

> "The enhanced performance of HVAC and lighting systems ... produces ... 1) lower energy costs; 2) lower maintenance costs; 3) lower repair and replacement costs; and 4) increased occupant productivity."

The diffusion model is combined with information on office building floorspace to generate two sets of annual estimates. These estimates are: 1) an estimate of the cumulative total CBS installations in millions of square meters (millions of square feet) and (2) an estimate of the new CBS installations in millions of square meters (millions of square feet). To get the cumulative total CBS installations in millions of square meters (millions of square feet), the value of $P_\eta(t)$ is multiplied by the total amount of office floorspace. The total amount of office floorspace is equal to 973 million m^2 (10.5 billion ft^2).[5] Following the commercial introduction of CBS products and services in 2003, the cumulative totals rise steadily until the end of the study period. To get the new CBS installations in millions of square meters (millions of square feet), the value of $N_\eta(t)$ is multiplied by the total amount of office floorspace. These values rise over the period 2003 to 2012, then level off, and then decline.

Table 2 summarizes how cost savings by category and in total are calculated. Cost savings begin in 2003, the year in which CBS products and services first become commercially available. The energy cost savings for each year, recorded in Column 2, is equal to the product of three terms: 1) unweighted energy cost savings per square meter (per square foot) of $1.71 ($0.16); 2) a weighted time series for energy; and 3) the cumulative total CBS installations in millions of square meters (millions of square feet) for that year.

Because energy prices change over time, it is necessary to develop an energy price index to apply to per unit energy cost savings.[3] The maintenance cost savings for each year, in Column 3, is equal to the product of maintenance cost savings per square meter (per square foot) of $1.60 ($0.15) and the cumulative total CBS installations in millions of square meters (millions of square feet) for that year. The repair and replacement cost savings for each year, in Column 4, is equal to the product of repair and replacement cost savings per square meter (per square foot) of $0.66 ($0.06) and the cumulative total CBS installations in millions of square meters (millions of square feet) for that year. The productivity cost savings for each year, in Column 5, is equal to the product of productivity cost savings per square meter (per square foot) of $4.20 ($0.39) and the cumulative total CBS instal-

Year	Annual Cost Savings in Millions of 1997 Dollars By Category Due to				Total Cost Savings by Year in Millions of 1997 Dollars
	Reduced Energy Consumption	Reduced Maintenance	Reductions in Repairs and Replacements	Increased Occupant Productivity	
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6) (2)+(3)+(4)+(5)
2003	1.287	1.240	0.496	3.223	6.245
2004	2.314	2.250	0.900	5.851	11.314
2005	4.148	4.073	1.629	10.589	20.440
2006	7.463	7.332	2.933	19.064	36.791
2007	13.179	13.074	5.230	33.993	65.476
2008	23.095	22.929	9.171	59.615	114.810
2009	39.361	39.105	15.642	101.673	195.781
2010	63.615	63.812	25.525	165.912	318.864
2011	96.340	97.684	39.074	253.979	487.076
2012	134.581	137.838	55.135	358.379	685.934
2013	170.312	177.992	71.197	462.779	882.281
2014	202.723	211.864	84.746	550.846	1,050.179
2015	228.673	236.571	94.628	615.085	1,174.958

Table 2: Cost savings by category and in total by year (2003–2015).

lations in millions of square meters (millions of square feet) for that year.

The cost savings by category for each year recorded in *Table 2* are based on the cumulative total CBS installations up to and including that year. The reason for using cumulative total CBS installations rather than new CBS installations is that CBS products and services, once installed, continue to generate cost savings. Recall that CBS-related cost savings are based on comparisons between the base case and the CBS alternative. Thus, office buildings that installed the CBS alternative in 2003 continue to accrue cost savings *vis-à-vis* the base case throughout the remainder of the study period.

In addition to cost savings by category, *Table 2* also contains total cost savings by year. These cost savings are recorded in Column 6. Total cost savings for each year equal the sum of each category's cost savings for that year. Total cost savings, denominated in millions of 1997 dollars, increase steadily between 2003 and 2015.

Table 3 summarizes how to calculate the present values of cost savings nationwide by year and in total. The table also includes information on total cost savings, additional CBS-related installation costs, net cost savings, and the discount factor needed to translate yearly net cost savings into yearly present value cost savings nationwide.

Year	Total Cost Savings in Millions	Additional Cost to Install CBS Products and Services in Millions	Net Cost Savings in Millions by Year	Single Present Value Factor by Year	Present Value of Net Cost Savings Nationwide by Year in Millions
Col. (1)	Col. (2)	Col. (3)	Col. (4) (2) – (3)	Col. (5)	Col. (6) (4) × (5)
2003	6.245	8.263	–2.018	0.666	–1.345
2004	11.314	6.738	4.576	0.623	2.850
2005	20.440	12.151	8.289	0.582	4.824
2006	36.791	21.729	15.063	0.544	8.193
2007	65.476	38.280	27.196	0.508	13.825
2008	114.810	65.697	49.113	0.475	23.333
2009	195.781	107.842	87.940	0.444	39.046
2010	318.864	164.715	154.149	0.415	63.966
2011	487.076	225.813	261.264	0.388	101.323
2012	685.934	267.693	418.241	0.362	151.590
2013	882.281	267.693	614.587	0.339	208.182
2014	1,050.179	225.813	824.366	0.317	260.973
2015	1,174.958	164.715	1,010.243	0.296	298.894
					TOTAL 1,175.655

Table 3: Computation of present value cost savings nationwide by year and in total.

The years for which present values are calculated are listed in Column 1 of *Table 3*. Column 2 of *Table 3* contains total cost savings by year in millions of 1997 dollars. The total cost savings for each year is transferred from the respective row of Column 6 of *Table 2*. The additional cost to install CBS products and services for each year is recorded in Column 3 of *Table 3*. This cost equals the product of the additional cost to building owners and managers of $10.76 per square meter ($1.00 per square foot) and new CBS installations for that year. These costs first increase, then level off, and finally begin to decline. The difference between total cost savings and the additional costs to install CBS products and services equals net cost savings.

Column 4 of *Table 3* records net cost savings for each year in millions of 1997 dollars. Note that net cost savings are negative in 2003, after which they become positive and increase steadily. The calculated value of the single present value factor for each year is recorded in Column 5 of *Table 3*. The single present value factor is used to convert future values of net cost savings to present values. All entries are calculated using a real discount rate of 7%. Because 1997 is the base year, the single present value factor is pegged to that year. The single present value factor for any given year, Y, equals $(1.07)^{1997-Y}$ where $2003 \leq Y \leq 2015$. The present value of cost savings nationwide by year is recorded in Column 6 of *Table 3*. It equals the product of the net cost savings for that year, in Column 4, and the single present value factor, in Column 5. Note that the present value of cost savings nationwide is negative in 2003, after which it becomes positive and increases steadily.

Because the entries in Column 6 are in present value terms, they can be summed to get total cost savings nationwide over the entire study period. Total cost savings exceed $1.1 billion ($1,176 million in present value 1997 dollars).

Conclusions

Although the $1.1 billion magnitude of national cost savings is impressive, does it indicate that investment in CBS products and services by individual owners and operators will be cost effective? The answer to that question is almost certainly yes. Consider the case of the earliest adopters of CBS products and services, those owners and operators expected to invest in 2003. The aggregate investment made by these owner/operators was $8.3 million (see Column 3 of *Table 3*). Their first year's cost savings were $6.2 million (see Column 2 of *Table 3*). Not bad, but still a net loss after one year.

However, once installed, CBS products

and services continue to generate cost savings. For the earliest adopters, these savings measured in present value 1997 dollars, amount to $37.2 million. For every dollar invested in 2003 approximately $4.50 is returned (i.e., a savings-to-investment ratio of 4.5). This equates to an adjusted internal rate of return of approximately 20% per year over the period 2003 through 2015. These returns indicate that CBS's are an emerging technology whose time has come.

Note

* CBS-related research and development costs by BFRL, either actual expenditures or planned expenditures, are not included in the results presented in this article. Readers interested in how these costs were used to estimate the return on the public sector's CBS-related investment are referred to the NIST CBS impacts report.[3]

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